# MPPT Solar Light

**D/N: WAS-20C1EN**

## Introduction

Solar lights utilise solar energy as their energy source which have their battery packs charged using a photovoltaic panel. Traditionally solar lights usually adopt Schottky buck direct charging, resulting in lower charging power and less solar energy utilisation. These advanced solutions use PWM for charging control. By adding an MCU to manage the lithium battery charging, the charging power can be adjusted to provide energy improvements but still not reaching the maximum point. However, MPPT (Maximum Power Point Tracking) is a charging mechanism which has the ability to optimise the disadvantages mentioned above.

Holtek's MPPT charging solar light solution uses a combination of a battery management MCU, the BP45FH4NB, and a low-power PIR module, the BM22S4221-1. The BP45FH4NB includes two high voltage I/Os which can directly drive MOS transistors and multiple operational amplifiers and comparators for voltage/current detection and protection. Efficient solar charging with a tracking efficiency of up to 98% can be achieved using an MPPT algorithm. The BM22S4221-1 module is composed of a BA45F6622 main control MCU, an optical lens and a passive infrared sensor, with low power consumption and an internal software filtering algorithm to implement a sensitive human body sensing function.

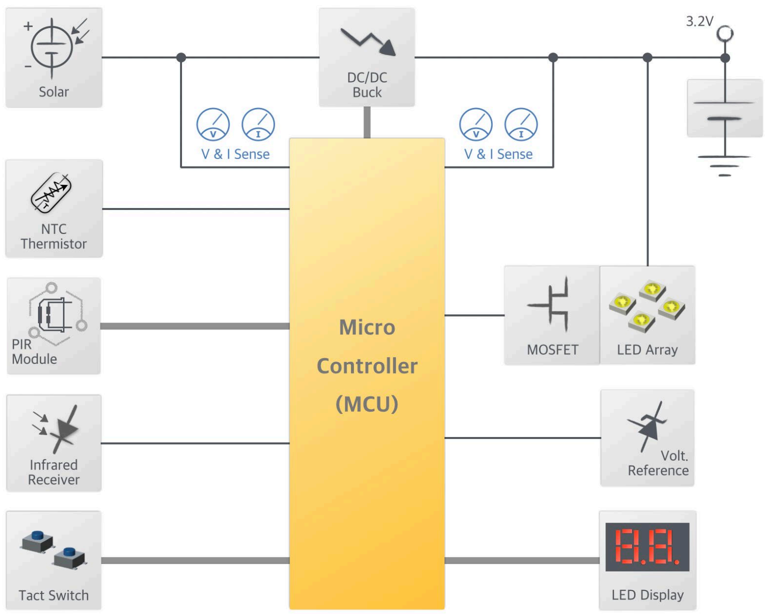


**Figure 1. Application Block Diagram**

### Application Areas

Solar light charging, energy storage sensor lights.

### Solution Characteristics

1. Simplified components: integrated level shifted output pins, over/under voltage and over current protection functions

   The BP45FH4NB provides two level shifted output pins which can directly drive the high-side PMOS and low-side NMOS transistors. An over current protection function and an over/under voltage protection function are also provided to ensure battery charging/discharging safety.

2. Efficient charging management: MPPT charging, charging power optimisation, solar energy utilisation optimisation

   The MPPT controller can detect the voltage and current of the photovoltaic panel in real time. It can therefore track the maximum power using MCU calculations and adjust the operating voltage of the photovoltaic panel allowing it to operate at its point of maximum power in the present environment to charge the lithium battery pack. Compared with traditional solar controllers, this method creates a way of achieving higher photovoltaic panel power efficiency.

# Operating Principles

Solar lights are mainly composed of a photovoltaic panel, a controller, a lithium battery pack and LEDs. The photovoltaic panel is used to convert light energy into electricity. The controller uses a photovoltaic panel as its energy input source and a lithium battery pack for energy storage. The lithium battery is then used to drive the LEDs.

The MPPT method will detect voltage and current using a controller. It will calculate the output power of the photovoltaic panel and adjust the duty cycle of the MOSFET to change the output current and voltage of the photovoltaic panel accordingly. By measuring and calculating changes in the photovoltaic panel's power and voltage before and after the current changes, the next cycle changes can be determined. If the changes are moving in the right direction, then the photovoltaic panel output power will be increased. Here the changes will continue in the same direction for the next cycle. However, if the changes move things in the wrong direction, then change to the opposite direction. This procedure of changes and observations should continue until the output power of the photovoltaic panel reaches its maximum point.

The human body sensing module generates a trigger signal when a human body approaches which allows the controller to automatically turn on the light.

# Functional Description

## Solution Features

- Lithium battery parameter: 20000mAh@3.2V, four single-cell batteries in parallel
- Charging voltage: DC 4~7V – uses a photovoltaic panel as the power supply
- Charging current: up to 6A
- Charging power control: MPPT power tracking
- MPPT tracking efficiency: up to 98%
- Control method: MCU software controlled MPPT power tracking
- Remote control: infrared remote control
- Human body sensing: PIR
- PIR sensing distance: 10m

## Solution Functions

The physical product is shown in Figure 2, 3 and 4.

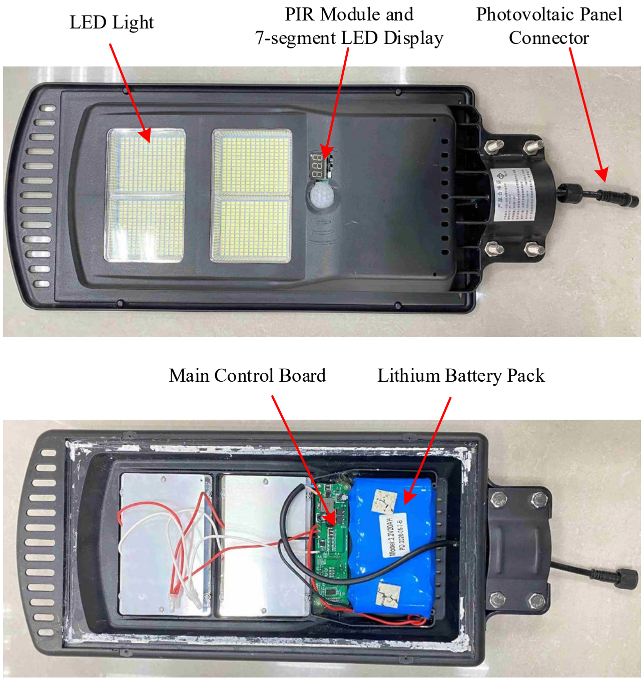


**Figure 2**

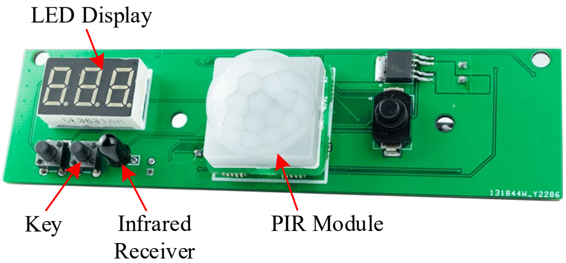


**Figure 3**

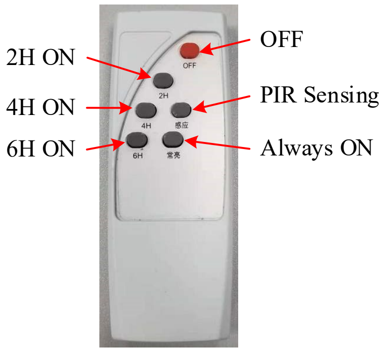


**Figure 4**

This product can illustrate a working comparison between MPPT charging and buck direct charging. The advantages of the MPPT charging can be seen intuitively due to a greater charging power and a higher solar ultilisation rate.

This design includes an operating mode and a demonstration mode, where the operating status is displayed using a 3-digit 7-segment LED display and the operating parameters are displayed using a 3-digit 7-segment LED display. The detailed operating steps are provided below. Note that the information shown by the LED displays correspond to the present operating state which is set by Key1, Key2 and remote control. Charging mode is set by keys, lighting mode is set by remote control.

1. Master Switch Key

   The master switch key is located on the front side of the LED. It is used to turn on/off the lithium battery circuit. The lithium battery can be charged or discharged only after the master switch key is turned on. After turning on the key and powering on, the system defaults to the MPPT charging mode. In this condition, the LED displays 1 which indicates that the system is in the charging operating mode.

2. Lighting Mode Switching

   When using a remote control for lighting mode switching, the switching action is confirmed if no more actions take place within a 0.5s time period. The LED will display the system operating status after the lighting mode has been switched. There are six lighting modes in total, which can be cycled through using remote control and which correspond to the remote control keys one by one, as shown in the table below.

| Mode | Lighting Time | LED Display |
|---|---|---|
| PIR Sensing | Triggered by PIR sensing, 15 seconds each time | SEN |
| Timing1 | Switch to PIR sensing mode after 2 hours lighting | 2H |
| Timing2 | Switch to PIR sensing mode after 4 hours lighting | 6H |
| Timing3 | Switch to PIR sensing mode after 6 hours lighting | 6H |
| Always On | Always On | ON |
| Always Off | Always Off | OFF |

**Table 1**

After a lighting mode has been confirmed, the LED display will cycle through the system operating status, photovoltaic panel output voltage, battery pack voltage and battery pack discharging power.

3. Charging Mode Switching

After entering the demonstration mode using Key1 and Key2, there are two sub-modes. MPPT charging mode is switched by Key1 and photovoltaic panel buck direct charging mode is switched by Key2, as shown below.

| Mode | LED Display |
|---|---|
| MPPT charging | 1 |
| Photovoltaic panel buck direct charging | 2 |

**Table 2**

For these two modes, the LED display will cycle through the system operating status, photovoltaic panel output voltage, battery pack voltage, photovoltaic panel output power, battery pack absorbed power and conversion efficiency of the system buck topology. The remote control can be used to exit the charging mode and to enter the lighting mode.

The comparison results of the display contents of the Schottky buck direct charging and MPPT charging shows that the former charging mechanism reduces the photovoltaic panel output voltage to a level near the battery pack voltage. Although this has a high conversion efficiency, it results in a small amount of absorbed power. However, the MPPT charging mechanism makes the photovoltaic panel output voltage vary around a certain value, resulting in a larger photovoltaic panel output power and battery pack absorbed power.

This proves that MPPT charging can make greater use of the photovoltaic panel output power to implement a maximum power tracking function. When tested using solar simulators, the MPPT efficiency of this kind of solar light can be up to 98%, which is above the average of MPPT products on the market.

# Solution Design Description

This solution uses the BP45FH4NB as the master MCU, providing a program memory capacity of 4K, 21 bidirectional I/O ports, multiple timer modules, high voltage output pins for directly driving MOS transistors and an integrated LDO. With regard to analog features, the device includes a multi-channel 12-bit A/D converter, two over current protection functions and an over/under voltage protection function.

The solution is composed of the BP45FH4NB main control board and the PIR module, among which is the BA45F6622 module application circuit. The following section will focus on the main control board introduction.

## Hardware Description

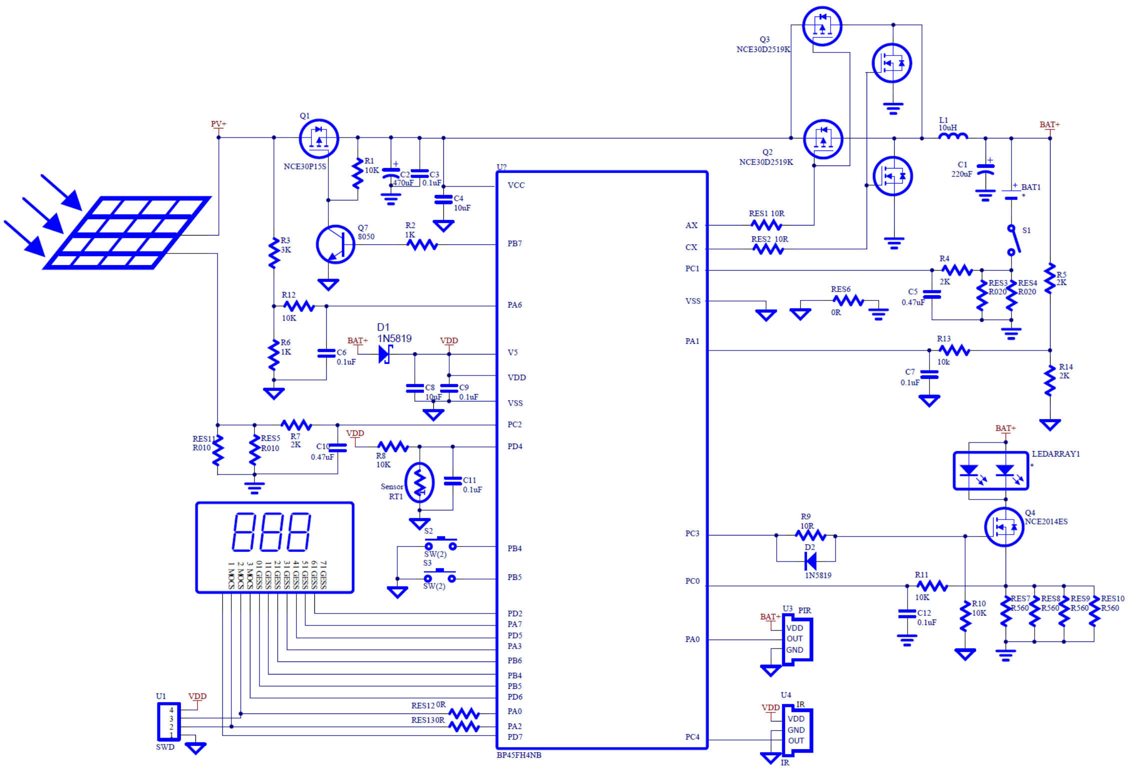


**Figure 5. Main Control Circuit Diagram**

1. The solar light uses the MPPT principle for lithium battery pack charging. The MPPT controller, which is implemented using the BP45FH4NB as shown in Figure 5, detects the photovoltaic panel voltage via the PA6 pin and detects the current via the PC2 pin in real time. This allows tracking of the photovoltaic panel maximum power using MCU calculations. The controller adjusts the PWM (AX and CX outputs) of the buck topology to make the photovoltaic panel always operate at its maximum output power point. The MPPT controller can also detect the voltage and current of the lithium battery pack in real time. When the photovoltaic panel's maximum output power exceeds the lithium battery pack's maximum receiving power, the battery pack will be charged using the latter's power value.

2. Human body sensing is implemented by the BM22S4221-1 PIR module as shown by U2 in Figure 5. The human body infrared detection digital module is based on the pyroelectric principle. This module has low power consumption, a UART communication interface as well as an internal software filtering algorithm to improve the PIR sensor's reliability. It can be applied to a wide application range including smart home appliances, monitoring systems and basic security detection, etc. When a human body near the solar light is detected, a trigger signal will be generated to automatically turn on the light.

   The BM22S4221-1 module in this solution operates by generating an alarm signal. Its STATUS pin, which corresponds to the OUT pin in U2, will output a high level for 3s when a human body is detected or output a constant low level if no human body is detected.

3. The human machine interface includes keys, LED display and infrared remote control. The keys and remote control are used to set the solar light operating mode such as light always off, light

always on, light periodic on/off, human body detection triggered on/off, etc. The LED display shows the solar light operating parameters including battery voltage, battery current, charging power, charging efficiency, etc.

## Layout and Hardware Considerations

Figure 6 and Figure 7 show the front and back sides of the PCB layout of the main control board.

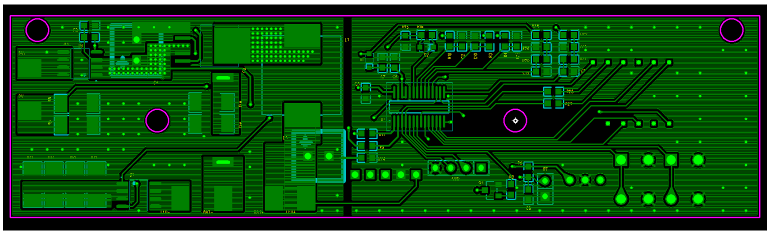

Figure 6

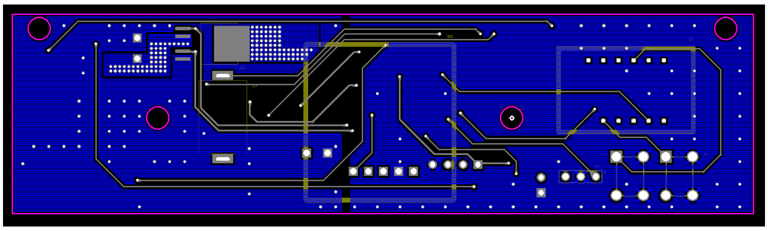

Figure 7

## PCB BOM List

**Bill of Materials**

Bill of Materials For PCB Document [MPPT_LIGHT_VOL2.0.sch]

| | | |
|---|---|---|
| **Source Data From:** | **MPPT_LIGHT_VOL2.0.sch** | |
| **Project:** | **MPPT_LIGHT_BP45FH4NB** | |
| **Variant:** | **None** | |
| Creation Date: | 2022/1/4 | 上午 11:02:11 |
| Print Date: | 30-Aug-22 | 1:53:57 PM |

| Designator | Comment | LibRef | Footprint | Description | Quantity |
|---|---|---|---|---|---|
| D1,D2 | 1N5819 | 1N5819 | SOD-323 | Schottky diode | 2 |
| U1 | BP45FH4NB | BP45FH4NB | SSOP_28PIN_150MIL_0.635PITCH | MCU | 1 |
| K2 | BUTTON | BUTTON | BUTTON_2PIN | KEEP BUTTON | 1 |
| C9 | CAP | 220uf | CAP+ | Capacitor | 1 |
| C4 | CAP | 470uf | CAP+ | Capacitor | 1 |
| C1,C3,C6,C8,C12,C13 | CAP | 0.1uf | 0603 | Capacitor | 6 |
| C2,C10 | CAP | 0.47uf | 0603 | Capacitor | 2 |
| C5,C7 | CAP | 10uf | 0603 | Capacitor | 2 |
| NEC | HDR3X1 | NEC | REMOTE | Header, 3-Pin | 1 |
| SWD | HDR4X1 | SWD | SIP4 | Header-4PIN | 1 |
| PIR | HDR_5X1 | PIR | PIR | Header, 5-Pin | 1 |
| K1,K3 | KEY1 | KEY | BUTTON | Header, 5-Pin | 2 |
| L1 | L | 10uH | 13_13 | Inductor | 1 |
| Q1 | NCE2014ES | NCE2014ES | SOIC-8_150mil | N-Channel Power MOSFET | 1 |
| Q3,Q5 | NCE30D2519K | NCE30D2519K | TO252-4L | P&N Channel Power MOSFET | 2 |
| Q2 | NCE30P15S | NCE30P15S | SOIC-8_150mil | P-Channel Power MOSFET | 1 |
| R7 | NTC | 10K | SIP2 | 10K NTC | 1 |
| BAT+,BAT-,LED+,LED-,PV+,PV- | P | P | PAD_SMD_RECTANGLE | PAD, Cathodic line | 6 |
| R24,R27,R28 | RES | 0R | 0603 | Resistor | 3 |
| R1,R6,R15 | RES | 10K | 0603 | Resistor | 3 |
| R9,R11,R16 | RES | 10R | 0603 | Resistor | 3 |
| R4,R20,R21 | RES | 10k | 0603 | Resistor | 3 |
| R2 | RES | 1K | 0603 | Resistor | 1 |
| R23 | RES | 1K | 0603 | Resistor | 1 |
| R3,R10,R25,R26 | RES | 2K | 0603 | Resistor | 4 |
| R22 | RES | 3K | 0603 | Resistor | 1 |
| R5,R8 | RES | R010 | RES_2010 | Resistor | 2 |
| R12,R13 | RES | R020 | RES_2010 | Resistor | 2 |
| R14,R17,R18,R19 | RES | R560 | RES_2010 | Resistor | 4 |
| Q4 | S8050 | S8050 | SOT-23 | NPN Bipolar Transistor | 1 |
| U2 | SEGMENT3 | SEGMENT | SEGMENT | Digital tube | 1 |
| | | | | | 62 |

| **Approved** | **Notes** |
|---|---|
| | |

Table 3. Main Control Board BOM List

## Software Description

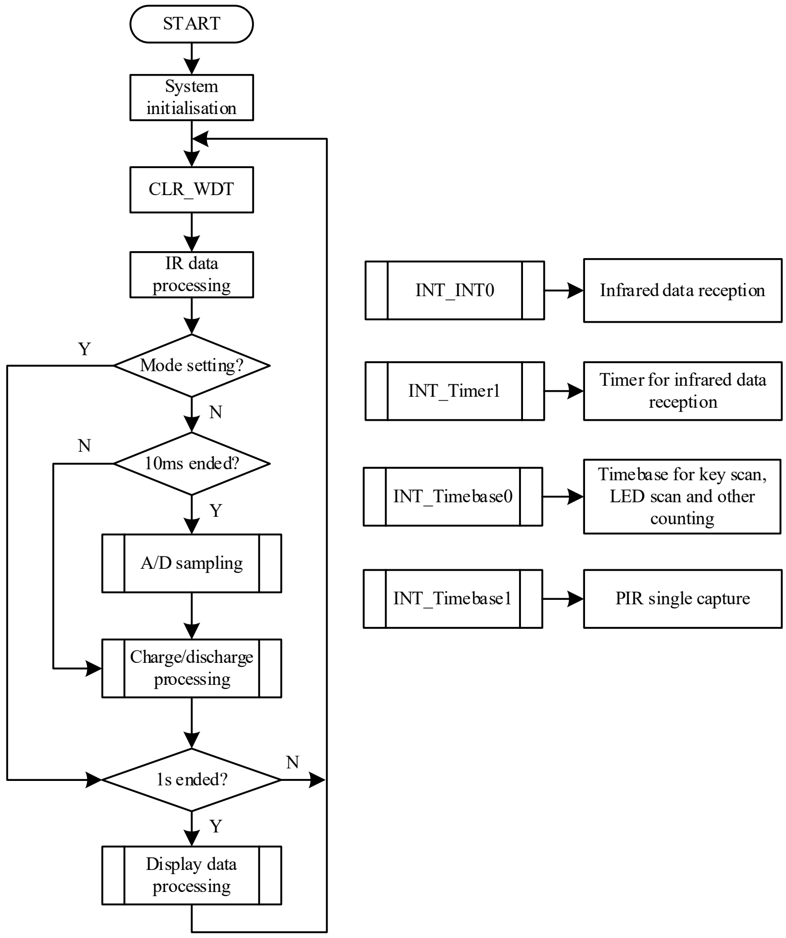


**Figure 8. Main Program Flowchart**

### Initialisation

After the batteries are connected for the first time, the program will first initialise some default data, mainly the system register configuration and the LED lighting mode setting, etc., for which no initialisation will be repeated afterwards.

### Main Loop

- In the main loop, the program will analyse the IR infrared remote control signal and execute the corresponding action.
- Execute a key scan operation every 5ms and act accordingly when a key is pressed.
- An infrared signal or key signal will trigger the system to enter the setting mode. If no new signal is received within 0.5s, confirm the present signal command and then exit the setting mode.
- Execute A/D sampling of the voltage and current every 10ms and determine whether an over voltage or over current condition has occurred.
- Execute charging if the system input voltage meets the requirement
- Display the system operating parameters every 1s which include operating mode, voltage, current, etc.

**A/D Sampling**

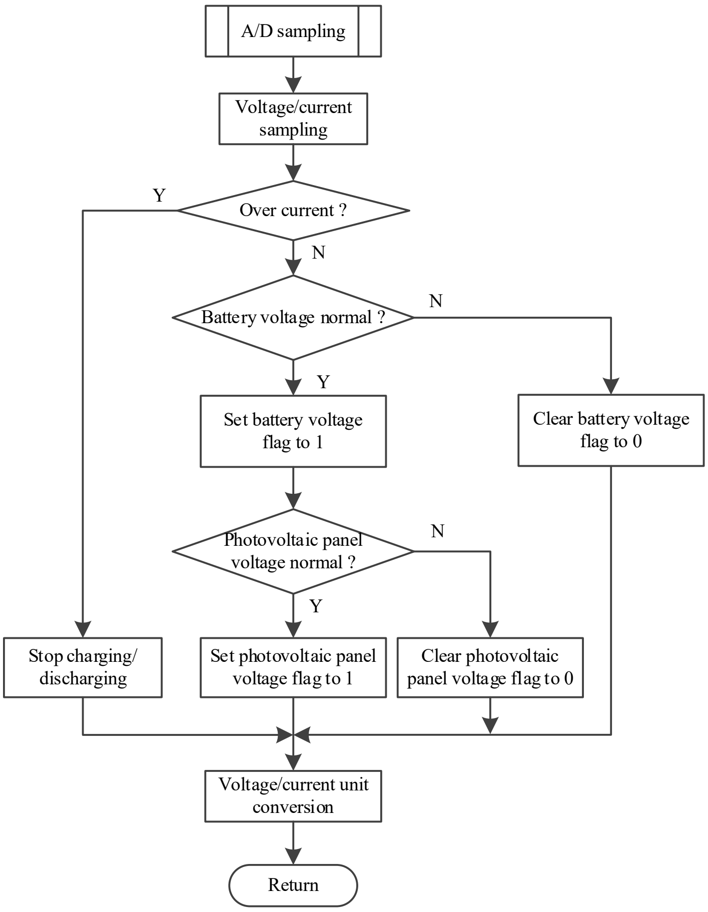


**Figure 9. A/D Sampling Subroutine Flowchart**

The A/D sampling subroutine is used to sample the voltage and current values of the photovoltaic panel and battery, judge abnormalities and perform a unit conversion on the values. The over current threshold value is 6A, the normal voltage range of the battery is 2V~3.65V indicated by the f_bat_vol_ok flag, and the normal voltage range of the photovoltaic panel is 3V~10V indicated by the f_pv_vol_ok flag.

**Charge/Discharge Processing**

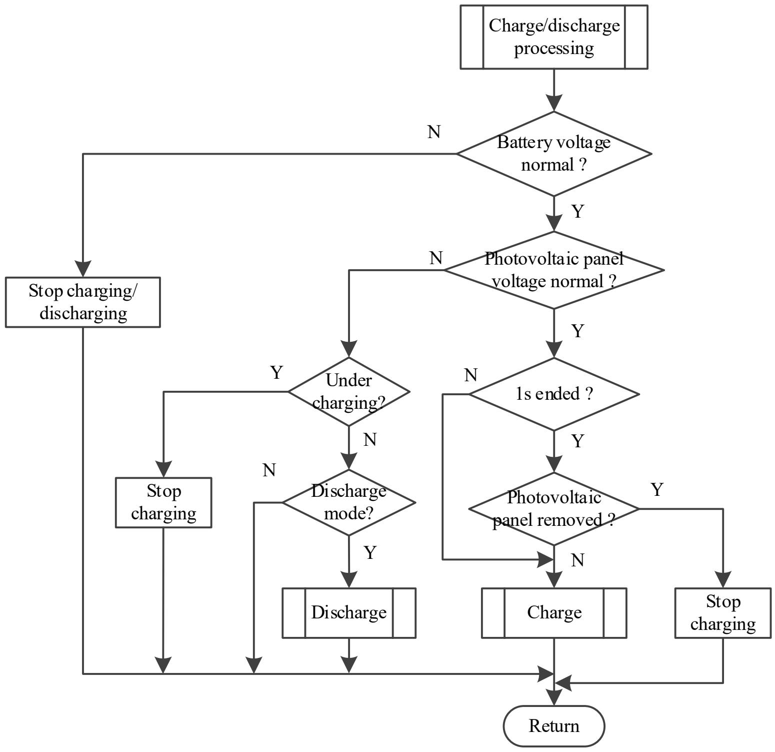


**Figure 10. Charge/Discharge Subroutine Flowchart**

The charge/discharge processing subroutine executes a charge or discharge operation according to the external conditions and then executes this based on the mode setting.

**Charge**

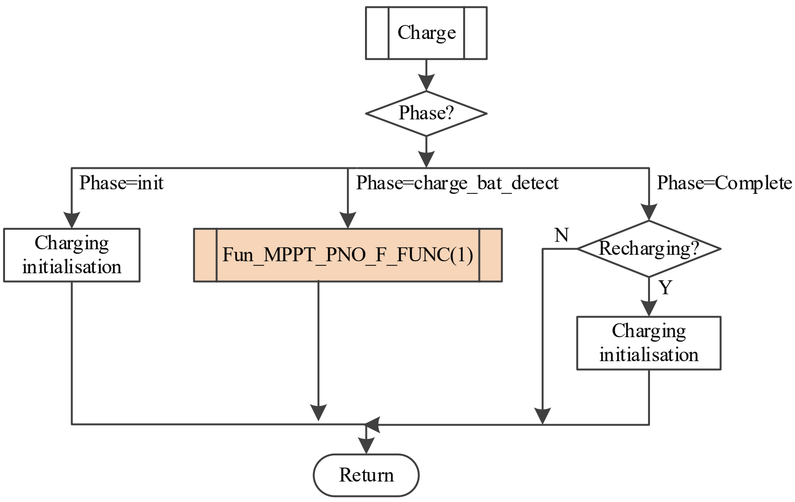


**Figure 11. Charge Subroutine Flowchart**

There are three charging methods which are MPPT charging, direct charging, and charging while discharging. The charging mode setting can only be set via keys. The MPPT library will select appropriate charging power within the set battery voltage and charging current limit. The battery will stop charging and indicate that it is fully charged when the charging current reduces to a level below the cut-off charging current or when the battery voltage is higher than 3.65V. The battery will be recharged if the voltage reduces to a value below 3.5V after being fully charged. Before the lithium battery charging power reaches its maximum limit, the MPPT power tracking function is used to track the photovoltaic panel's maximum power for lithium battery charging.

**Discharge**

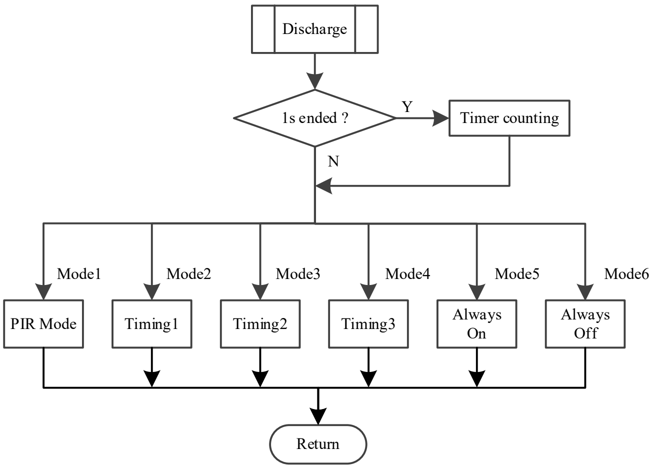


**Figure 12. Discharge Subroutine Flowchart**

There are six discharging modes including the PIR mode, three timing modes, always on mode and always off mode, which are set by the infrared remote control. In the PIR mode, which occurs during night time, that is when the photovoltaic panel voltage is lower than 3V, the PIR module will turn on the light for 10s when it detects a human body approaching. The 10s countdown will be refreshed each time a PIR trigger signal is generated. In the timing modes the light will be turned on for a fixed time of 2, 4 or 6 hours automatically during night time. The light will remain on in the always on mode and remain off in the always off mode.

**Key Scanning**

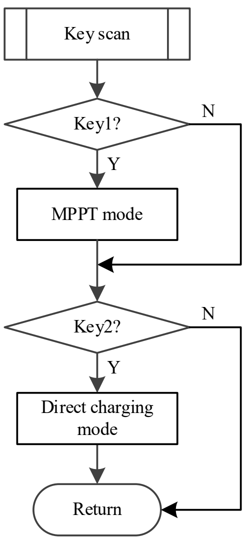


**Figure 13. Key Scanning Subroutine Flowchart**

MPPT mode is switched by Key1 and direct charging mode is switched by Key2.

**Interrupt Functions**

The PIR module output signal is polled by the Timebase interrupt where a high voltage will trigger the lighting action.

The infrared remote control data is determined using the timing length based on Timer1 and this data is read upon the receipt of an INT0 capture edge. The six keys of the remote control correspond to the six operating modes (Mode1~Mode6) in the discharge flowchart.

Timebase0 is a timer used for key scanning, the LED display scan and other functions.

**MPPT Library Description**

1. Resource Utilisation

   The MPPT Library for the P&O (Perturbation and Observation) method occupies 0.5K words of ROM and 24 bytes of RAM.

2. Parameter Description

| Parameter Name | Description | Unit |
|---|---|---|
| MPPT_Duty_sum | Total number of duty levels | - |
| MPPT_Duty_min | Duty lower limit | - |
| MPPT_Duty_max | Duty upper limit | - |
| MPPT_CHG_BATVMax | Maximum MPPT battery voltage value | 10mV |
| MPPT_CHG_BATVMaxAdjust | Maximum MPPT battery voltage ripple value | 10mV |
| MPPT_CHG_BATI_Min | Minimum MPPT charging current value | 10mA |
| MPPT_CHG_BATI_MaxAdjust | Maximum MPPT battery current ripple value | 10mA |
| MPPT_PV_V_min | Minimum solar panel voltage value | 10mV |
| MPPT_PNO_Time | Timing for re-perturbation | Library calling cycle |

**Table 4**

3. Variable Description

| Global Variable | Type | Description | Unit |
|---|---|---|---|
| pv_V | unsigned int | Solar panel voltage | 10mV |
| Bat_I | unsigned int | Battery current | 10mA |
| Bat_V | unsigned int | Battery voltage | 10mV |
| BAT_I_max_Duty | unsigned char | Maximum battery charging duty | - |
| BAT_I_Prev | unsigned int | Previous battery sample current | 10mA |
| MPPT_CHG_DeltaBat_Imin | unsigned char | Maximum battery charging current ripple value | 10mA |
| Duty | unsigned char | Duty value | - |
| Dutysize | signed char | Step size of the duty adjustment- initial value is 1 | - |
| Mppt_process | unsigned char | MPPT process - initial value is 0 | - |
| MPPT_CHG_BATI_Max | unsigned int | Maximum battery charging current | 10mA |
| pv_V | unsigned int | Solar panel voltage | 10mV |
| Bat_I | unsigned int | Battery current | 10mA |
| Bat_V | unsigned int | Battery voltage | 10mV |

**Table 5**

4. Subroutine Description

There is a subroutine in the MPPT library which is called during battery charging.

| **Function Name** | unsigned char Fun_MPPT_PNO_F_FUNC(u8 Chgmode) |
|---|---|
| Function | MPPT algorithm library function |
| Input | Unsigned char Chgmode :<br>0x00 : disable; 0x01 : enable |
| Output | Return unsigned char Value :<br>0x00 : error, external charging power supply should be cut off;<br>0x01 : Normal Mode, Duty is adjustable<br>0x80 : OCP or OVP |
| Description | This function is called during the MPPT charging for charging power adjustment. |

**Table 6**

# Test Data

Voltage and current measurement point description.

- Input voltage: photovoltaic panel positive terminal on the PCB board – PV+
- Input current: the sampling resistor at the photovoltaic panel negative terminal on the PCB board – PV-
- Output voltage: lithium battery positive terminal on the PCB board – BAT+
- Output current: the sampling resistor at the lithium battery negative terminal on the PCB board – BAT-

1. Charging power and efficiency - simulate a 20W@6V, 3.33A photovoltaic panel with a maximum output power of 10W

| | **Input Voltage (V)** | **Input Current (A)** | **Input Power (W)** | **Output Voltage (V)** | **Output Current (A)** | **Output Power (W)** | **Charging Efficiency (%)** | **Energy Utilisation (%)** |
|---|---|---|---|---|---|---|---|---|
| Buck Direct Charging | 4.22 | 1.853 | 7.82 | 3.285 | 1.853 | 6.08 | 77.8 | 78.2 |
| MPPT Charging | 6.0 | 1.65 | 9.9 | 3.348 | 2.75 | 9.2 | 92.9 | 98.05 |

**Table 8**

2. Charging power and efficiency - simulate a 20W@6V, 3.33A photovoltaic panel with a maximum output power of 20W

| | **Input Voltage (V)** | **Input Current (A)** | **Input Power (W)** | **Output Voltage (V)** | **Output Current (A)** | **Output Power (W)** | **Charging Efficiency (%)** | **Energy Utilisation (%)** |
|---|---|---|---|---|---|---|---|---|
| Buck Direct Charging | 4.71 | 3.67 | 17.28 | 3.38 | 3.67 | 12.4 | 71.2 | 86.4 |
| MPPT Charging | 6.0 | 3.3 | 19.8 | 3.4 | 5 | 17 | 85.85 | 99 |

**Table 9**

3. Charging power and efficiency - simulate a 10W@6V, 1.66A photovoltaic panel with a maximum output power of 5W

| | **Input Voltage (V)** | **Input Current (A)** | **Input Power (W)** | **Output Voltage (V)** | **Output Current (A)** | **Output Power (W)** | **Charging Efficiency (%)** | **Energy Utilisation (%)** |
|---|---|---|---|---|---|---|---|---|
| Buck Direct Charging | 3.984 | 0.93 | 3.705 | 3.27 | 0.93 | 3.04 | 82.1 | 74.1 |
| MPPT Charging | 6 | 0.82 | 4.92 | 3.29 | 1.4 | 4.606 | 93.6 | 98.4 |

**Table 10**

4. Charging power and efficiency - simulate a 10W@6V, 1.66A photovoltaic panel with a maximum output power of 10W

| | Input Voltage (V) | Input Current (A) | Input Power (W) | Output Voltage (V) | Output Current (A) | Output Power (W) | Charging Efficiency (%) | Energy Utilisation (%) |
|---|---|---|---|---|---|---|---|---|
| Buck Direct Charging | 4.27 | 1.854 | 7.916 | 3.30 | 1.854 | 6.12 | 77.28 | 79.16 |
| MPPT Charging | 6 | 1.647 | 9.882 | 3.345 | 2.75 | 9.198 | 93.08 | 98.82 |

**Table 11**

5. DC-DC conversion efficiency: input voltage ranges from 5V to 8V, output voltage is 3V. The curves in the following figure show the relationship between the buck efficiency from 5V~8V to 3V and the charging current. The curve values shown in the figure correspond to the efficiency values of stepping down the voltage from 5V to 3V.

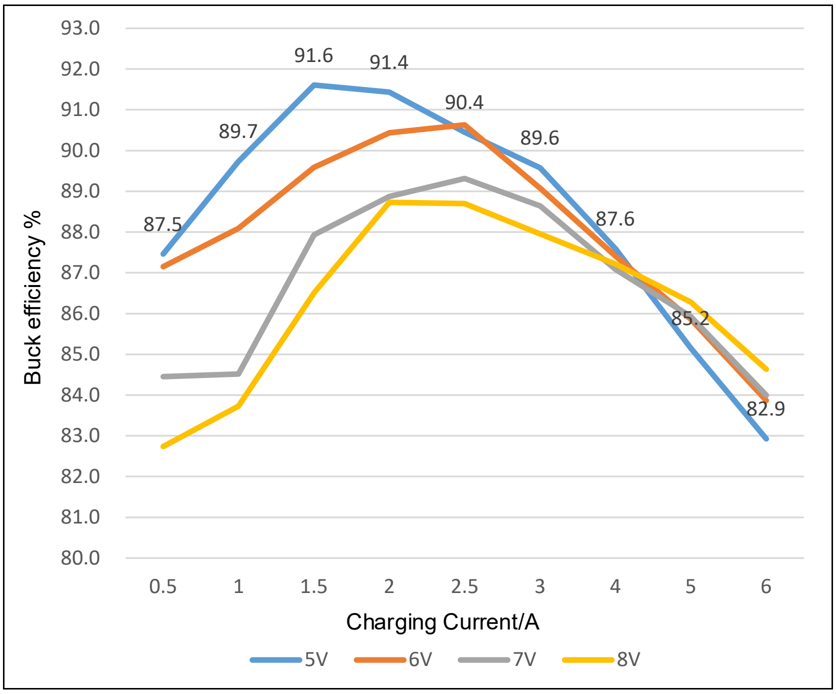


**Figure 14**

# Solution Comparison

| | Holtek Solution | Traditional Solutions |
|---|---|---|
| Function | Solar charging, MPPT power tracking, higher power | Solar charging, low voltage direct charging, low PWM charging power |
| Program | High energy utilisation | Low energy utilisation |
| Cost | MCU integrates over current, over/under voltage protection functions | Need additional protection circuits |

**Table 12**

# Conclusion

This article has introduced the Holtek MPPT charging solar light solution which uses a combination of the BP45FH4NB master control MCU and the BM22S4221-1 module. The BP45FH4NB provides two level shifted output pins which can be used to directly drive the high-side PMOS and low-side NMOS transistors. The MCU also provides over current, over/under voltage protection functions for battery charging and discharging safety. These features when combined with the BM22S4221-1 module can form a complete MPPT charging solar light solution. The BM22S4221-1 module has the advantages of low power consumption, a UART communication interface as well as an internal software filtering algorithm to improve the reliability of the PIR sensor and implement a sensitive human body sensing function.

# Reference Material

Reference files: BP45FH4NB, BA45F6622, BM22S4221-1 datasheets.

For BM22S4221-1 information, contact Anchip technical service engineer.

For more details, refer to Holtek website: www.holtek.com

# Versions and Modification Information

| Date | Author | Issue | Modification Information |
|---|---|---|---|
| 2022.01.14 | 劉暉楊 | V1.10 | Change the master control MCU to BP45FH4NB |
| 2021.01.30 | 譚林祥 | V1.00 | First Version |

# Disclaimer

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